# Compressed Natural Gas

The principal CleanFleet findings concerning the use of CNG were that:

1. Exhaust emission levels of most pollutants from the natural gas vans (NGVs) were lower than from vans using any of the other fuels that were demonstrated. The potential of the nonmethane organic gases in the NGV exhaust to generate ozone in the atmosphere was 90 to 95 percent less than the ozone-forming potential (OFP) of gasoline exhaust. The OFP of the NGV exhaust did not degrade significantly over mileage during the two-year demonstration.

2. Infrastructure is a key factor in gaining sufficient penetration of NGVs into fleet use to realize the low emissions level benefits of NGVs for an urban area. Capital and operating costs to install and operate CNG compressors, cascade storage, and dispensers can be significant. If NGVs are brought into buildings, the local fire marshall and code officials may require extensive changes to the heating and ventilation system and installation of flammable gas detectors. To optimize the economics of using NGVs, a fleet operator may need to modify the operating practices it is accustomed to using for gasoline or diesel vehicles.

   Infrastructure was a key factor in estimating the cost for a fleet operator to introduce and use CNG in 50 vans in Los Angeles in 1996. The estimated costs ranged from 40.4 to 45.9 cents per mile of vehicle travel (assuming 20,000 miles per year per van) if the fleet operator owns the natural gas compressor. Then the gas is bought from the utility at low pressure. If the compressor station is owned by a fuel provider and the fleet operator purchases compressed gas, the cost may range from 40.1 to 41.5 cents per mile. In both cases, the range of costs reflects the effects of different fleet operating practices.

3. The reliability and required maintenance of NGVs reflected the state of development of the technology demonstrated. The NGVs that were production vans required less maintenance than the NGVs that were after-market modifications of gasoline vans. Fleet operators need to examine closely the reliability of after-market NGVs before committing to their purchase and use.

4. The efficiency of NGVs in using the energy content of CNG was less than the efficiency of their gasoline controls, and this too reflected the state of technology development. This, coupled with the use of relatively heavy fuel storage tanks of limited capacity, gave the NGVs a driving range that was only marginally acceptable for urban fleet operations. Optimizing NGVs for fuel efficiency and using lighter tanks with more storage volume can ameliorate this concern.

## Vehicle Technology

The CleanFleet NGVs represented a range of technologies. The Dodge vans were among the first production NGVs offered by Chrysler Corporation. They featured a 5.2-liter V8 engine, sequential multiport electronic fuel injection (SMPI), and a catalyst system designed for natural gas exhaust. The Dodge control vans used 5.2-liter gasoline engines. The Ford vans were modified by Ford to operate on CNG. They featured 4.9-liter, inline engines, limited calibration of a SMPI system, a compression ratio of 11:1 (compared to the Ford gasoline engine compression ration of 8.8:1), and a standard catalyst system for gasoline exhaust. The Ford control vans used 4.9-liter engines as well. The Chevrolet NGVs were gasoline vans with natural gas compatible engines (5.7-liter V8) that were modified to operate on CNG with an IMPCO Technologies fuel delivery system. Fuel was delivered to the engine through a gas ring upstream of the throttle body. An Engelhard catalyst designed for natural gas exhaust was employed. The Chevrolet control vans used 4.3-liter V6 engines.

### Emissions Benefits

Exhaust emissions from the NGVs were generally much less than emission levels from the gasoline control vans, and the low emisison levels of the NGVs were stable as the vans accumulated mileage. The potential of the nonmethane organic gases (NMOG) in the exhaust (which is regulated to a specific mass emissions level) to contribute to forming ozone (or, more loosely, smog) in the atmosphere was 90 percent less than the OFP of the NMOG in the exhaust of the corresponding control vans. Emission levels of nitrogen oxides ($NO_x$) from the NGVs were less than the $NO_x$ levels from the control vans for two of the OEMs (49 and 43 percent) and greater for the other manufacturer (Ford, 63 percent), reflecting the state of the technology. Emissions of carbon monoxide ranged from 68 to 77 percent less for the NGVs compared to their control vans. In general, emission levels of the four air toxics addressed in the CleanAir Act Amendments (CAAA) of 1990 were also reduced compared to the control vans. These four compounds are formaldehyde, acetaldehyde, benzene, and 1,3-butadiene. Most striking were the low mass emissions of NMOG and the corresponding low OFP of the NGV exhaust.

### Operations

To achieve these emission benefits, the NGVs must, of course, be placed into service and perform reliably. The production Dodge NGVs and the NGVs modified by Ford were purchased without problem. However, purchase and delivery of the Chevrolet NGVs that were modified by a third party were stalled by issues of product liability and liability for the vans during modification. In the intervening years, as more vehicles were modified outside of the CleanFleet project, these issues have been clarified for major distribution channels (e.g., Ford’s Qualified Vehicle Manufacturer program). Nevertheless, for locally run after-market modifications, a fleet operator needs to examine closely the third-party modifier’s responsibility for the vehicles and subsequent warranty and product liability.

Infrastructure also must be put in place for NGVs. For CleanFleet, this included providing a fueling station and modifying the building into which NGVs were driven and parked overnight. Southern California Gas Company installed two natural gas compressors, cascade storage, and a dispenser at the FedEx host site. The two compressors were installed in parallel to provide redundancy. Over the two-year demonstration period, the system operated reliably although issues were dealt with such as (1) carry-over of lubricant from the compressors through the cascade system and dispenser into the vans, (2) inadequate capacity to fill all 21 vans in rapid succession, and (3) failure of one of the compressors. In addition, natural gas in the reference cylinder in the dispenser had to be replenished a few times to maintain its pressure and enable the system to fill the NGVs all the way to 3,000 pounds per square inch pressure. The compressor facility was a major mechanical system on the property and, as such, required preventive and unscheduled maintenance. An important decision for a fleet in implementing compressed natural gas as a motor fuel is how to supply the CNG: (1) by installing and operating a compressor facility and purchasing the natural gas uncompressed from the local utility or (2) by purchasing the gas compressed from the local utility (in which case the utility is responsible for the compressor facility).

The building into which FedEx brought its vans also required preparation for the NGVs. The local fire marshall and building code officials required that the building ventilation be increased to five air changes per hour and linked to a system of flammable gas detectors that were installed near the ceiling throughout the building. Also, pre-existing open-flame unit heaters were disconnected. As officials become more accustomed to natural gas as a transportation fuel, their requirements might be modified. In any event, a lesson learned from the project was to work closely with local officials throughout the process of incorporating NGVs into the fleet.

Once in operation, the safety, fuel economy, maintenance requirements, and reliability of the vans were closely monitored. The FedEx NGV fleet operated safely throughout the demonstration. A few leaks on the vans and in the compressor facility were quickly stopped. Limited measurements of natural gas vapors in the air when the vans were fueled found gas concentrations to be far below any health-based levels set by the Occupational Safety and Health Administration (OSHA) and the American Conference of Government and Industrial Hygienists (ACGIH).

The relative fuel economy of the NGVs compared to their gasoline controls was determined from laboratory-based emissions measurements as well as daily operations. The average relative fuel economy (or energy efficiency) based upon the two types of determinations was +3.6 and -2.6 percent for the Ford vans, -4.3 and -9.4 percent for the Dodge vans, and -12.8 and -16.4 percent for the Chevrolet vans. Figure 3 shows the results, with the bars representing the 95 percent statistical confidence interval about the mean (shown as the horizontal line within the bars). When the bar is completely above or below the line of zero percent difference (e.g., Chevrolet), it can be said with 95 percent confidence that the mean energy efficiency of the AFVs differed from that of their control vans. The low efficiency for the Chevrolet vans (which is statistically significant) reflects the different engines (5.7-liter CNG vs. 4.3-liter gasoline), as well as limited optimization of the fuel delivery system. These findings point to some loss in fuel efficiency for model year 1992 NGVs compared to gasoline vans. Coupled with the fuel storage capacity of the vans, these efficiencies yielded driving ranges on fully fueled NGVs ranging from 116 to 139 miles for a FedEx delivery route of average length and number of starts and stops. These ranges were adequate for over half the delivery routes in FedEx urban operations. However, some routes proved too long for the NGVs, and gasoline vans had to be used on these routes.

Maintenance requirements on the NGVs reflected the state of technology. The production NGVs and those modified by the manufacturer required minor maintenance. The Chevrolet NGVs equipped with IMPCO's AFE system required maintenance on hardware and software throughout the demonstration, again reflecting development problems. The average availability of the Chevrolet, Dodge, and Ford NGVs was 94, 93, and 94 percent (Figure 4). The corresponding availability of the control vans using regular unleaded (UNL) gasoline was 95, 91, and 98 percent.

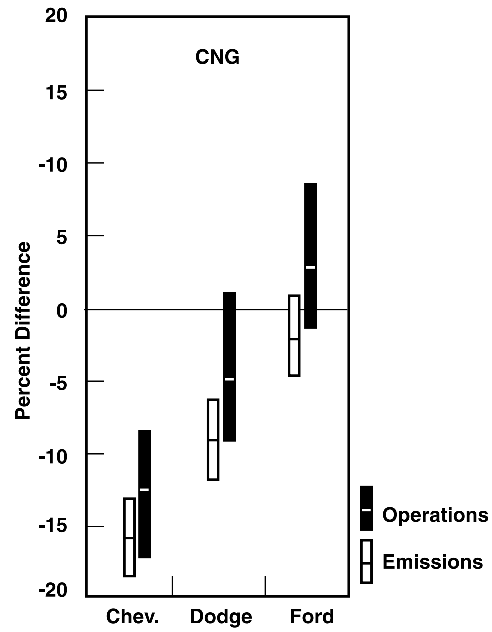


**Figure 3. Relative fuel economy (efficiency) for CNG vans was compared to the control vehicles.**

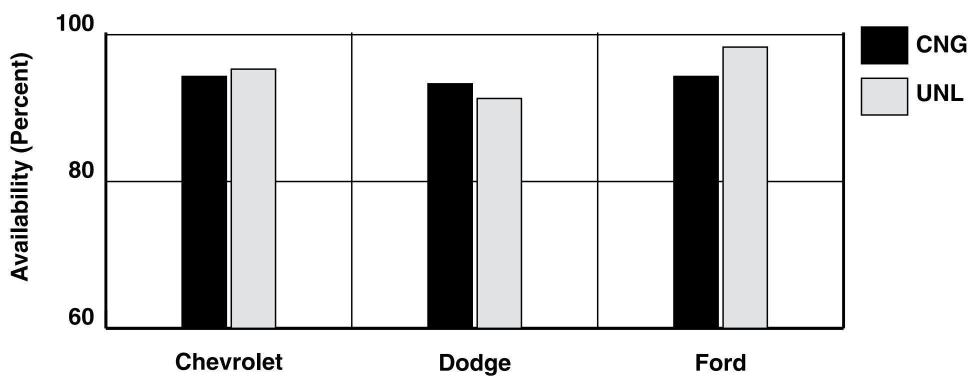


**Figure 4. The availability of CNG and control vans is shown.**

FedEx employees who participated in the demonstration had a uniformly positive attitude about using a “clean-burning” van. Attitudes about NGV performance were mixed for two reasons. First, none of the employees believed that they could rely on the fuel gauge to indicate the quantity of fuel. Coupled with a shorter driving range than the gasoline vans, this uncertainty caused anxiety in the drivers. Second, the problems related to stalling and rough operation of the vans with the AFE fuel system caused many of the drivers to be apprehensive about their safety, fearing that a stall could lead to a traffic accident. The consensus among the drivers was that the NGVs, in general, had less horsepower and only a marginally acceptable driving range. Nevertheless, their attitude about CNG showed a positive shift during the demonstration as they gained experience with the previously “unknown” fuel.

## Fleet Economics

The experience of the CleanFleet demonstration was used as a starting point to develop an estimate of the cost to a fleet for using any one of the alternative fuels in the 1996 time frame. A case study was developed based on the assumption that a commercial package delivery service in Los Angeles had a fleet of 150 vans, of which 50 were to be powered by an alternative fuel. Fueling was assumed to be on site, similar to current FedEx practice. Using the cost factors shown in Table 2, the total cost to a fleet in cents per mile for the 50-van fleet were estimated. (In this case, 1 cent per mile equals $10,000 per year.) Estimates were made both before and after corporate income tax and with and without incentives.

Figure 5 shows a range of cost estimates for a fleet using NGVs before income tax and without incentives. The four cases on the left reflect the assumption that a fleet owns and operates the natural gas compressor station. The two cases on the right reflect the assumption that a fleet operator purchases CNG

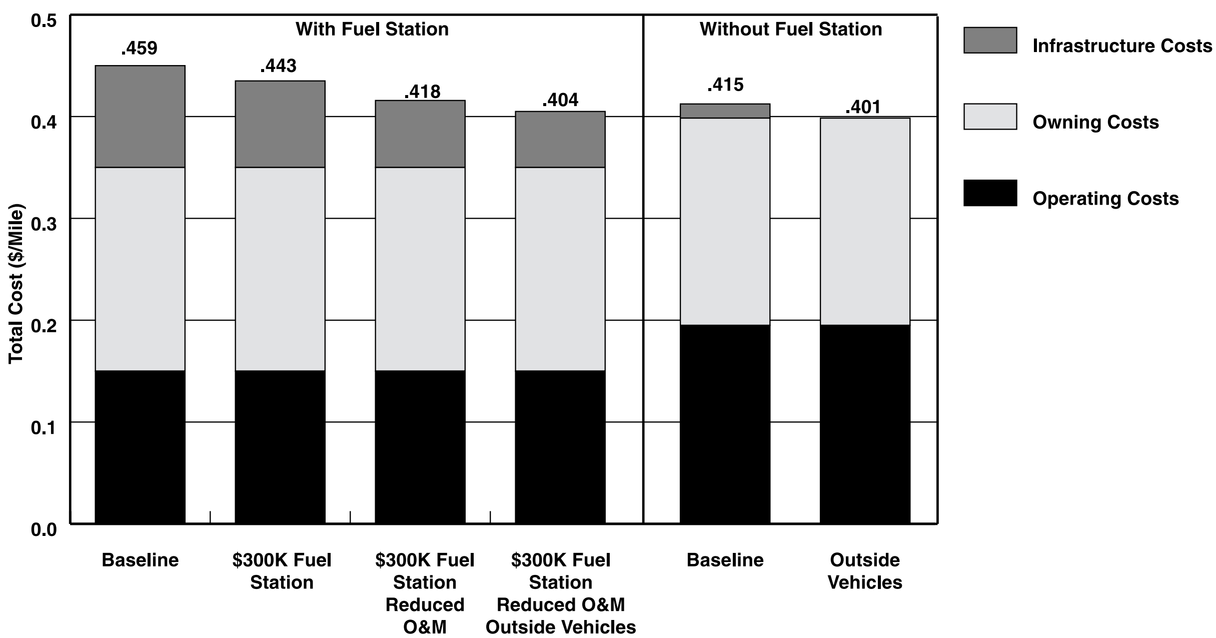


**Figure 5. Costs were estimated for a CNG fleet in a 1996 economic case study.**

from a utility that owns and operates the compressor station. The baseline case on the far left (45.9 cents per mile) is closest to CleanFleet experience (i.e., redundancy in compressors, fast fueling, and building modifications). Relaxing requirements for redundancy in the compressor and achieving smaller operating and maintenance (O&M) costs for it are reflected in the next two estimates of 44.3 and 41.8 cents per mile. Finally, if no building modifications are required (because the vans are parked outside), the cost is reduced further to 40.4 cents per mile. These costs and those for the purchase of CNG (41.5 cents per mile with building modifications and 40.1 cents per mile without building modifications) compare to an estimated cost of 34.6 cents per mile for 50 vans using regular gasoline. The most important finding from the economic analysis of CNG use by a fleet is that the decisions that a fleet operator makes on options for operation can have a large impact on the cost of using this fuel.